POLYMER –CONJUGATED, GLYCOSYLATED NEUBLASTIN

FIELD OF THE INVENTION

The invention relates to protein chemistry, molecular biology, neurobiology, neurology, and pain management.

BACKGROUND OF THE INVENTION

Neurotrophic factors are naturally-occurring proteins that regulate neuronal survival during development and regulate plasticity and structural integrity of the adult nervous system. These neurotrophic factors can be classified into superfamilies, families, subfamilies and individual species based on their structure and function.

Neurotrophic factor superfamilies include the fibroblast growth factor (FGF) superfamily, the neurotrophin superfamily, and the transforming growth factor-β (TGF-β) superfamily. The glial cell line-derived neurotrophic factor (GDNF)-related ligands are a family of proteins within the TGF-β superfamily. GDNF-related ligands include GDNF, persephin (PSP), neurturin (NTN) and neublastin (NBN; known as artemin or enovin). Members of the GDNF-related ligand family are distinguished by, among other things, their seven conserved cysteine residues. These residues form intramolecular and intermolecular disulfide bridges and give rise to the tertiary and quaternary structure of the dimerized polypeptide ligand. Members of the family also induce signaling through a multicomponent receptor complex consisting of a glycosylphosphatidylinositol (GPI)-anchored co-receptor of the GFRα family, a member of the GDNF-related ligand subfamily, and the RET tyrosine kinase receptor.

Activated RET initiates a signal transduction cascade that is responsible, at least in part, for the downstream effects of GDNF-related ligands.

Neublastin is classified within the GDNF family because it shares regions of homology with other GDNF ligands including the seven cysteine motif (*e.g.*, as described in EP02/02691, PCT publications US02/02319 and US02/06388), and because binds to, and activates, the RET receptor as part of a GFRα complex. Neublastin is highly selective for binding to the GFRα3-RET receptor complex. In

that respect, neublastin contains unique sub regions in its amino acid sequence as compared with other members of the GDNF-related ligand family.

Administration of neublastin is potentially useful in the treatment of diseases associated with neuronal degeneration and dysfunction. However, neublastin is rapidly cleared by the body, which may affect the neublastin dosing paradigm required in therapeutic applications. There is a need for molecules that display the biological activity of neublastin while exhibiting enhanced potency.

SUMMARY OF THE INVENTION

It has been discovered that when a neublastin protein, i.e., a dimer, is internally glycosylated and amino terminal-conjugated to a water-soluble synthetic polymer, e.g., polyethylene glycol (PEG), bioavailability and serum half-life are significantly enhanced. Therefore, in vivo efficacy is achieved at lower doses.

Based on this discovery, the invention features a dimer containing a first neublastin polypeptide and a second neublastin polypeptide, wherein: (a) at least one of the polypeptides is glycosylated; (b) at least one of the polypeptides is conjugated at its N-terminus to a water-soluble synthetic polymer; and (c) neither of the polypeptides is conjugated to a water-soluble synthetic polymer at a position other than the N-terminus.

The neublastin polypeptide(s) can be, e.g., NBN113 (SEQ ID NO:2), NBN140 (SEQ ID NO:6), NBN116 (SEQ ID NO:7), NBN112 (SEQ ID NO:8), NBN111 (SEQ ID NO:9), NBN110 (SEQ ID NO:10), NBN109 (SEQ ID NO:11), NBN108 (SEQ ID NO:12), NBN107 (SEQ ID NO:13), NBN106 (SEQ ID NO:14), NBN105 (SEQ ID NO:15), NBN104 (SEQ ID NO:16), NBN103 (SEQ ID NO:17), NBN102 (SEQ ID NO:18), NBN101 (SEQ ID NO:19), NBN100 (SEQ ID NO:20) and NBN99 (SEQ ID NO:21). A preferred polypeptide for incorporation into the dimer is NBN104 (SEQ ID NO:16).

In some embodiments, the amino acid sequence of the first neublastin polypeptide and the second neublastin polypeptide are the same. Preferably, the

water-soluble synthetic polymer is a polyalkylene glycol, e.g., polyethylene glycol (PEG).

Preferably, the average total molecular weight of the polyalkylene glycol moiety or moieties conjugated to the dimer is 10-50 kDa; more preferably 15-45 kDa; and most preferably 20-40 kDa. The polyalkylene glycol moiety can be linear or branched.

The invention provides a composition comprising the dimer of claim 1 and a pharmaceutically acceptable carrier.

The invention provides a method of treating neuropathic pain in a mammal, e.g., a human patient. The method includes administering to the mammal a therapeutically effective amount of a dimer of the invention. The invention provides a method of treating tactile allodynia in a mammal. The method includes administering to the mammal a therapeutically effective amount of a dimer of the invention. The invention provides a method of treating thermal hyperalgesia in a mammal. The method includes administering to the mammal a therapeutically effective amount of a dimer of the invention. The invention provides a method of activating the RET receptor in a mammal. The method includes administering to the mammal an effective amount of a dimer of the invention.

In some embodiments of the invention, the therapeutically effective amount is from 0.1 μg/kg to 1000 μg/kg. In some embodiments, the therapeutically effective amount is from 1 μg/kg to100 μg/kg. In some embodiments, the therapeutically effective amount is from 1 μg/kg to 30 μg/kg. In some embodiments, the therapeutically effective amount is from 3 μg/kg to 10 μg/kg. Preferably, the route of administration is intramuscular or subcutaneous.

Unless otherwise defined, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs. Although methods and materials similar or equivalent to those described herein can be used in the practice of the invention, suitable methods and materials are described below. All publications, patent applications, patents, and other references mentioned herein are incorporated by reference in their

entirety. In the case of conflict, the present specification, including definitions, will control.

Unless otherwise stated, any reference to a neublastin polypeptide amino acid residue number corresponds to the numbering in SEQ ID NO:1.

As used herein, "consensus neublastin" means the sequence of SEQ ID NO:1

As used herein, "neublastin polypeptide" means a polypeptide that (1) displays at least one biological activity of neublastin when dimerized as a homodimer, and (2) includes an amino acid sequence at least 90% identical to amino acids 8-113 of SEQ ID NO:2.

As used herein, "wild-type neublastin polypeptide" means a polypeptide whose amino acid sequence is a naturally-occurring neublastin polypeptide sequence. Examples of wild-type neublastins are human neublastin (SEQ ID NO:2), mouse neublastin (SEQ ID NO:3), and rat neublastin (SEQ ID NO:4).

Percent identity between amino acid sequences can be determined using the BLAST 2.0 program (available at www.ncbi.nlm.nih.gov/BLAST) or a subsequent version thereof. Sequence comparison can be performed using an ungapped alignment and using the default parameters (Blossom 62 matrix, gap existence cost of 11, per residue gap cost of 1, and a lambda ratio of 0.85). The mathematical algorithm used in BLAST programs is described in Altschul et al., 1997, *Nucleic Acids Research* 25:3389-3402.

Other features and advantages of the invention will be apparent from the following detailed description and claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a broken line plot summarizing data showing substantial reversal of fully established tactile allodynia by subcutaneous administration of a homodimer of NBN104 wherein each monomer is conjugated to a PEG moiety at its amino terminus, and glycosylated at position 95 ("2 X 20 kDa PEG NBN104"), in rats with L5/L6 spinal nerve ligation.

FIG. 2 is a broken line plot summarizing data showing substantial reversal of fully established thermal hyperalgesia by subcutaneous administration of 2 X 20 kDa PEG NBN104 in rats with L5/L6 spinal nerve ligation.

FIG. 3 is an alignment of mature, wild-type neublastin sequences from human, mouse, and rat. Also shown is a consensus sequence based on the human, mouse and rat sequences.

FIG. 4 is a consensus sequence based on human, mouse and rat neublastin sequences, with optional amino acid substitutions indicated.

FIG. 5 is an alignment of the wild-type human neublastin prepro sequence, and three different mature, human neublastin sequences produced naturally by alternative post-translational processing.

FIG. 6 is an amino acid sequence alignment of various truncations of the 113-amino acid form of wild-type human neublastin that can be incorporated into dimers of the invention.

DETAILED DESCRIPTION OF THE INVENTION

Polymer-Conjugated, Glycosylated Neublastin Dimers

Dimers of the invention display activity in assays for biological activity of neublastin. For example, dimers of the invention are active in RET activation assays. Dimers of the invention display enhanced bioavailability and/or longer serum half-life relative to the corresponding dimer without the combination of polymer conjugation and glycosylation. In preferred embodiments of the invention, the polymer-conjugated, glycosylated dimer displays significantly increased potency *in vivo*, relative to the potency of the corresponding polypeptide without polymer conjugation and glycosylation.

In general, polypeptides incorporated into dimers of the invention retain at least one of the following features:

(i) seven conserved cysteine residues at positions corresponding to residues 16, 43, 47, 80, 81, 109, and 111 in SEQ ID NO:1;

(ii) amino acid residues as follows:

C at position 16, L at position 18, V at position 25, L at position 28, G at position 29, L at position 30, G at position 31, E at position 36, F at position 40, R at position 41, F at position 42, C at position 43, G at position 45, C at position 47, C at position 80, C at position 81, R at position 82, P at position 83, F at position 91, D at position 93, N at position 95, S at position 105, A at position 106, C at position 109 and C at position 111;

(iii) an LGLG repeat, an FRFC motif, a QPCCRP motif, and a SATACGC motif.

Preferably, the polypeptides retain all of the above features.

Examples of wild-type neublastin polypeptide amino acid sequences are presented in FIG. 3. Regarding wild-type neublastin polypeptides and sequences, see PCT publication WO 00/01815. A neublastin consensus sequence (consensus with respect to human, mouse and rat) is presented in FIG. 4.

The sequence of the human prepro neublastin (SEQ ID NO:5) is shown in FIG. 5. Three mature forms of human neublastin resulting from different post-translational processing have been identified. The three forms are:

(i) the 140 AA polypeptide designated NBN140 (SEQ ID NO:6);

(ii) the 116 AA polypeptide designated NBN116 (SEQ ID NO:7); and

(iii) the 113 AA polypeptide designated NBN113 (SEQ ID NO:2).

FIG. 5 is an alignment comparing the human prepro neublastin amino acid sequence and the three mature sequences. Line 1 provides the polypeptide of SEQ ID NO:5, line 2 provides the polypeptide of SEQ ID NO:6, line 3 provides the polypeptide of SEQ ID NO:7 and line 4 provides the polypeptide of SEQ ID NO:2. The seven conserved cysteine residues are designated by symbols ("*", "#", "+" and "|") to indicate the intramolecular (* with *, # with #, and + with +) and

intermolecular ("|") disulfide bridges formed in the mature dimerized neublastin ligand.

Neublastin polypeptides in dimers of the invention may be products of a protease cleavage reaction or a chemical cleavage reaction, or may be expressed directly from recombinant DNA construct. Alternatively, they can be chemically synthesized, e.g., using a commercial, solid phase synthesizer.

A preferred polymer-conjugated neublastin polypeptide dimer is a homodimer of NBN104 wherein each monomer is conjugated to a PEG moiety at its amino terminus, and glycosylated at position 95 ("2 X 20 kDa PEG NBN104"). In some embodiments, the polypeptide in the dimer consists essentially of amino acids 8-113 of SEQ ID NO:1.

In preferred embodiments of the invention, the dimer binds to GFRα3 and stimulates tyrosine phosphorylation of a RET polypeptide. In some embodiments, the dimer enhances survival of a sensory neuron, or reduces or reverses pathological changes of a sensory neuron. In some embodiments, the dimer enhances survival of an autonomic neuron or a dopaminergic neuron.

The invention provides a method for making a polymer conjugated glycosylated neublastin polypeptide dimer. The method includes providing a glycosylated neublastin dimer, e.g., from a eukaryotic cell, and conjugating at least one polypeptide in the dimer to a water-soluble, synthetic polymer, e.g., a polyalkylene glycol moiety.

Neublastin Polypeptides

Neublastin polypeptides can be produced by recombinant DNA techniques. For example, a nucleic acid sequence encoding a neublastin polypeptide can be inserted into a vector, *e.g.*, an expression vector, and the vector can be introduced into a suitable host cell. Suitable host cells are those that glycosylate polypeptides. Eukaryotic host cells are preferred. However, at least one bacterium, i.e., *Campylobacter jejuni*, contains an N-linked glycosylation system that can be transferred into bacterial host cells such as *E. coli* (Wacker et al., 2002, Science

298:1790-1793). Chemical modification and/or extension of a bacterial glycosylation can be achieved *in vitro*, using methods and materials known in the art. Thus, a glycosylation-competent bacterial system optionally can be used to produce neublastin polypeptides for use according to the invention.

Neublastin polypeptides suitable for use in the invention can be produced in a mammalian cell, *e.g.*, a human embryonic kidney ("HEK") cell such as a HEK 293 cell, a BHK21 cell, or a Chinese hamster ovary ("CHO") cell. Other suitable mammalian cells include PC12, HiB5, RN33b cell lines, human neural progenitor cells, and other cells derived from human cells, especially neural cells. Examples of immortalized human cell lines useful in practicing the invention include Bowes Melanoma cells (ATCC Accession No. CRL 9607), Daudi cells (ATCC Accession No. CCL 213), HeLa cells and derivatives of HeLa cells (ATCC Accession Nos. CCL 2, CCL 2.1, and CCL 2.2), HL-60 cells (ATCC Accession No. CCL 240), HT-1080 cells (ATCC Accession No. CCL 121), Jurkat cells (ATCC Accession No. TIB 152), KB carcinoma cells (ATCC Accession No. CCL 17), K-562 leukemia cells (ATCC Accession No. CCL 243), MCF-7 breast cancer cells (ATCC Accession No. BTH 22), MOLT-4 cells (ATCC Accession No. 1582), Namalwa cells (ATCC Accession No. CRL 1432), Raji cells (ATCC Accession No. CCL 86), RPMI 8226 cells (ATCC Accession No. CCL 155), U-937 cells (ATCC Accession No. CRL 1593), WI-38VA13 sub line 2R4 cells (ATCC Accession No. CLL 75.1), and 2780AD ovarian carcinoma cells (Van der Blick *et al., Cancer Res. 48*: 5927-5932, 1988). Secondary human fibroblast strains, such as WI-38 (ATCC Accession No. CCL 75) and MRC-5 (ATCC Accession No. CCL 171), also can be used.

Suitable non-mammalian host cells include *Xenopus laevis* oocyte ("XLO") and yeast cells such as *Pichia pastoris*. In some embodiments, the host cell is an insect cell such as an Sf9 cell.

Transformation of the host cell can be by any suitable method, including, e.g., infection (employing a virus vector), by transfection (employing a plasmid vector), using calcium phosphate precipitation, microinjection, electroporation, and lipofection. Methods and materials for eukaryotic host cell transformation are known in the art.

Neublastin polypeptides produced by transformed host cells can be isolated from the cells or from the host cell culture medium, using conventional protein purification techniques. Refolding steps can be employed as necessary.

Neublastin polypeptides can be modified using conventional methods and materials. One such method is site-directed mutagenesis, in which one or more nucleotides are changed in order to effect a predetermined substitution of one or more amino acids in a neublastin polypeptide. Suitable site-directed mutagenesis kits are commercially available, e.g., "Transformer Site Directed Mutagenesis Kit" (Clontech Laboratories, Palo Alto, Calif.).

Some embodiments of the invention involve neublastin polypeptides containing conservative amino acid substitutions. Conservative amino acid substitutions include substitutions within the following groups: valine, alanine and glycine; leucine, valine, and isoleucine; aspartic acid and glutamic acid; asparagine and glutamine; serine, cysteine, and threonine; lysine and arginine; and phenylalanine and tyrosine. The non-polar hydrophobic amino acids include alanine, leucine, isoleucine, valine, proline, phenylalanine, tryptophan and methionine. The polar neutral amino acids include glycine, serine, threonine, cysteine, tyrosine, asparagine and glutamine. The positively charged (basic) amino acids include arginine, lysine and histidine. The negatively charged (acidic) amino acids include aspartic acid and glutamic acid.

The glycosylated neublastin may be provided in any bioactive form, including the form of pre-pro-proteins, pro-proteins, mature proteins, phosphorylated proteins, non-phosphorylated proteins, truncated forms, or any other posttranslational modified protein. In some embodiments, a polypeptide of the invention has the amino acid sequence presented as SEQ ID NO:6, holding a glycosylated asparagine residue at position 122; or the amino acid sequence presented as SEQ ID NO:14, holding a glycosylated asparagine residue at position 95, or the analogous position in any neublastin polypeptide when aligned by, *e.g.*, ClustalW computer software.

In general, a dimer isolated from a mammalian cell, or other such cell able to glycosylate proteins, will be glycosylated at amino acid position 95. Methods of

glycosylating proteins *in vitro* are known in the art and may be employed to glycosylate neublastin polypeptides or polypeptide dimers if so desired.

Practice of the present invention can be carried out using conventional techniques of cell biology, cell culture, molecular biology, microbiology, recombinant DNA, protein chemistry, and immunology. Such techniques are described in general references. *See,* e.g., *Molecular Cloning: A Laboratory Manual*, 2nd Ed. (Sambrook et al., eds.), Cold Spring Harbor Laboratory Press, 1989; *DNA Cloning*, Vol. I and II (Glover, ed), 1985; *Oligonucleotide Synthesis*, (Gait, ed.), 1984; Mullis et al. U.S. Pat. No. 4,683,195; *Nucleic Acid Hybridization* (Haines et al., eds.), 1984; *Transcription and Translation* (Hames et al., eds.), 1984; *Culture of Animal Cells* (Freshney, ed) Alan R. Liss, Inc., 1987; *Immobilized Cells and Enzymes*, IRL Press, 1986; *A Practical Guide to Molecular Cloning*, 1984; *Meth. Enzymol.*, Vol. 154 and 155 (Wu *et al.*, eds), Academic Press, New York; *Gene Transfer Vectors for Mammalian Cells* (Miller et al., eds.), 1987, Cold Spring Harbor Laboratory; *Immunochernical Methods in Cell and Molecular Biology* (Mayer et al., eds.), Academic Press, London, 1987.

Polymer Conjugation of Neublastin Polypeptides

The polymer conjugated to a neublastin polypeptide is water-soluble. Preferably, the polymer is suitable for use in a pharmaceutical composition. Examples of suitable water-soluble polymers include PEG, copolymers of ethylene glycol/propylene glycol, carboxymethylcellulose, dextran, polyvinyl alcohol, polyvinyl pyrrolidone, poly-1, 3-dioxolane, poly-1, 3, 6-trioxane, ethylene/maleic anhydride copolymer, polyaminoacids (either homopolymers or random copolymers), and dextran or poly(n-vinyl pyrrolidone) PEG, propropylene glycol homopolymers, polypropylene oxide/ethylene oxide co-polymers, polyoxyethylated polyols (*e.g.*, glycerol), polyvinyl alcohol, and mixtures thereof.

Average molecular weight per polymer chain is chosen in accordance with the desired average total molecular weight of the polymer(s) conjugated per dimer, e.g., 10-50 kDa, 15-45 kDa, or 20-40 kDa per dimer. In PEG preparations, some molecules weigh more, some less, than the stated molecular weight. Thus, molecular

weight is typically specified as "average molecular weight." Various conjugation methods are known in the art. *See, e.g.*, EP 0 401384 (coupling PEG to G-CSF); Malik *et al.*, Exp. Hematol. 20: 1028-1035, 1992 (PEGylation of GM-CSF using tresyl chloride).

PEGylation can be carried out by any suitable PEGylation reaction. Various PEGylation chemistries are known in the art. *See, e.g.,* Focus on Growth Factors, 3 (2): 4-10, 1992; EP 0 154 316; EP 0 401 384; and the other publications cited herein that relate to PEGylation. The PEGylation may be carried out via an acylation reaction or an alkylation reaction with a reactive PEG molecule (or other suitable reactive water-soluble polymer).

PEGylation by acylation generally involves reacting an active ester derivative of PEG. Any known or subsequently discovered reactive PEG molecule may be used to carry out the PEGylation. A preferred activated PEG ester is PEG esterified to N-hydroxysuccinimide (NHS). As used herein, "acylation" includes without limitation the following types of linkages between the therapeutic protein and a water soluble polymer such as PEG: amide, carbamate, urethane, and the like. *See, Bioconjugate Chem.* 5: 133-140, 1994. Reaction conditions may be selected from any of those known in the PEGylation art or those subsequently developed, but should avoid conditions such as temperature, solvent, and pH that would inactivate the neublastin protein or polypeptide to be modified.

In general, PEGylation by acylation results in a poly-PEGylated polypeptide. In the case of neublastin, however, there are no lysine residues. Therefore, PEGylation by acylation can be employed to obtain a polypeptide PEGylated exclusively at the amino terminus. PEGylated polypeptides can be separated from the reaction mixture and unreacted polypeptides, by conventional techniques, e.g., dialysis, salting-out, ultrafiltration, ion- exchange chromatography, gel filtration chromatography and electrophoresis.

PEGylation by alkylation generally involves reacting a terminal aldehyde derivative of PEG with neublastin polypeptide or dimer in the presence of a reducing agent. In general, PEGylation by alkylation can result in poly-PEGylated polypeptides, and one can manipulate the reaction conditions to favor PEGylation at

at the amino terminus. However, since neublastin contains no lysine residues, such manipulation need not be done. The PEG groups are preferably attached to the protein via a -CH_2-NH- group, i.e., through an "alkyl" linkage.

The polymer molecules used in both the acylation and alkylation approaches may be selected from among water-soluble polymers as described above. The polymer selected should be modified to have a single reactive group, such as an active ester for acylation or an aldehyde for alkylation, preferably, so that the degree of polymerization may be controlled as provided for in the present methods. An exemplary reactive PEG aldehyde is PEG propionaldehyde, which is water stable, or mono C1-C10 alkoxy or aryloxy derivatives thereof (*see*, U.S. Patent 5,252,714). The polymer may be branched or unbranched. For the acylation reactions, the polymer(s) selected should have a single reactive ester group. For the present reductive alkylation, the polymer(s) selected should have a single reactive aldehyde group. For purposes of the invention, the PEG can be any of the forms of PEG known in the art for derivatization of other proteins, including mono-(C1-C10) alkoxy- and aryloxy-PEG.

Formulations

Compositions containing dimers of the invention may contain suitable pharmaceutically acceptable carriers. For example, they may contain excipients and/or auxiliaries that facilitate processing of the dimers into preparations designed for delivery to the site of action. Suitable formulations for parenteral administration include aqueous solutions of the active compounds in water-soluble form, for example, water-soluble salts. In addition, suspensions of the active compounds as appropriate oily injection suspensions may be administered. Suitable lipophilic solvents or vehicles include fatty oils, for example, sesame oil, or synthetic fatty acid esters, for example, ethyl oleate or triglycerides. Aqueous injection suspensions may contain substances that increase the viscosity of the suspension, for example, sodium carboxymethyl cellulose, sorbitol and dextran. Optionally, the suspension may also contain stabilizers. Liposomes also can be used to encapsulate the molecules of the invention for delivery into cells or interstitial spaces. Exemplary pharmaceutically

acceptable carriers are physiologically compatible solvents, dispersion media, coatings, antibacterial and antifungal agents, isotonic and absorption delaying agents, water, saline, phosphate buffered saline, dextrose, glycerol, ethanol and the like. In some embodiments, the composition comprises isotonic agents, for example, sugars, polyalcohols such as mannitol, sorbitol, or sodium chloride. In some embodiments, the compositions include pharmaceutically acceptable substances such as wetting or emulsifying agents, preservatives or buffers.

Compositions of the invention may be in a variety of forms, including, for example, liquid (*e.g.*, injectable and infusible solutions), dispersions, suspensions, semi-solid and solid dosage forms. The preferred form depends on the mode of administration and therapeutic application.

The composition can be formulated as a solution, micro emulsion, dispersion, liposome, or other ordered structure suitable to high drug concentration. Sterile injectable solutions can be prepared by incorporating the active ingredient in the required amount in an appropriate solvent with one or a combination of ingredients enumerated above, as required, followed by filtered sterilization. Generally, dispersions are prepared by incorporating the active ingredient into a sterile vehicle that contains a basic dispersion medium and the required other ingredients from those enumerated above. In the case of sterile powders for the preparation of sterile injectable solutions, the preferred methods of preparation are vacuum drying and freeze-drying that yields a powder of the active ingredient plus any additional desired ingredient from a previously sterile-filtered solution. The proper fluidity of a solution can be maintained, for example, by a coating such as lecithin, by the maintenance of the required particle size in the case of dispersion, and by surfactants. Prolonged absorption of injectable compositions can be achieved by including in the composition an agent that delays absorption. Examples of such agents are monostearate salts and gelatin.

The active ingredient can be formulated with a controlled-release formulation or device. Examples of such formulations and devices include implants, transdermal patches, and microencapsulated delivery systems. Biodegradable, biocompatible polymers can be used, for example, ethylene vinyl acetate, polyanhydrides,

polyglycolic acid, collagen, polyorthoesters, and polylactic acid. Methods for the preparation of such formulations and devices are known in the art. See *e.g.*, Sustained and Controlled Release Drug Delivery Systems, J. R. Robinson, ed., Marcel Dekker, Inc., New York, 1978.

Injectable depot formulations can be made by forming microencapsulated matrices of the drug in biodegradable polymers such as polylactide-polyglycolide. Depending on the ratio of drug to polymer, and the nature of the polymer employed, the rate of drug release can be controlled. Other exemplary biodegradable polymers are polyorthoesters and polyanhydrides. Depot injectable formulations also can be prepared by entrapping the drug in liposomes or microemulsions.

Supplementary active compounds can be incorporated into the formulation. For example, a dimer according to the invention can be coadministered with an analgesic.

Dosage regimens may be adjusted to provide the optimum desired response. For example, a single bolus may be administered, several divided doses may be administered over time, or the dose may be proportionally reduced or increased as indicated by the exigencies of the therapeutic situation. It is advantageous to formulate parenteral compositions in dosage unit form for ease of administration and uniformity of dosage. See generally, *Remington's Pharmaceutical Sciences* (Mack Pub. Co., Easton, PA 1980).

In addition to a dimer of the invention, a liquid dosage form may contain inert ingredients such as water, ethyl alcohol, ethyl carbonate, ethyl acetate, benzyl alcohol, benzyl benzoate, propylene glycol, 1,3-butylene glycol, dimethylformamide, oils, glycerol, tetrahydrofurfuryl alcohol, polyethylene glycols, and fatty acid esters of sorbitan.

Methods of treatment

The invention is useful for treatment of sensory neurons, retinal ganglion cells, neurons in the dorsal root ganglia, and neurons in any of the following tissues: the geniculate, petrosal and nodose ganglia; the vestibuloacoustic complex of the eighth

cranial nerve; the ventrolateral pole of the maxillomandibular lobe of the trigeminal ganglion; and the mesencephalic trigeminal nucleus.

Compositions and methods of the invention can be used to treat sensory neurons, autonomic neurons, or both. Nociceptive and mechanoreceptive neurons can be treated, e.g., A-delta fiber, C-fiber and A-beta fiber neurons. In addition, sympathetic and parasympathetic neurons of the autonomic system can be treated.

Neuropathic Pain

When used in treatment of neuropathic pain, a dimer of the invention can be administered alone or in conjunction with an analgesic agent. Examples of an analgesic agent include an opioid, an anti-arrhythmic, a topical analgesic, a local anaesthetic, an anticonvulsant, an antidepressant, a corticosteroid or non-steroidal anti-inflammatory drug (NSAID). Preferred analgesic agents are gabapentin ((1-aminomethyl)cyclohexane acetic acid); and pregabalin (S-(+)-4-amino-3-(2-methylpropyl) butanoic acid).

Dimers of the invention can be used in the treatment of pain associated with peripheral neuropathies. Peripheral neuropathies that can be treated according to this invention include trauma-induced neuropathies, physical damage to the brain, physical damage to the spinal cord, and stroke.

The invention also provides treatments of chemotherapy-induced neuropathies, other drug induced neuropathies, pathogen-induced neuropathies, toxin-induced neuropathies, vitamin-deficiency-induced neuropathies; idiopathic neuropathies; and diabetic neuropathies. The invention also can be used to treat mono-neuropathies, mono-multiplex neuropathies, and poly-neuropathies, including axonal and demyelinating neuropathies.

Examples of chemotherapy-induced neuropathies include neuropathies caused by exposure to chemotherapeutic agents such as taxol, taxotere, cisplatin, nocodazole, vincristine, vindesine or vinblastine. Examples of other drug induced neuropathies incluce neuropathies caused by ddI, DDC, d4T, foscarnet, dapsone, metronidazole, and isoniazid. Examples of toxin-induced neuropathies include neuropathies induced by alcoholism, vitamin B6 intoxication, hexacarbon intoxication, amiodarone,

chloramphenicol, disulfiram, isoniazide, gold, lithium, metronidazole, misonidazole, and nitrofurantoin. Examples of virus-induced neuropathies include neuropathies caused by a herpes zoster (which may lead to post-herpetic neuralgia), human immunodeficiency virus (HIV), and papilloma virus (HPV). Examples of vitamin-deficiency-induced neuropathies are those caused by vitamin B12 deficiency, vitamin B6 deficiency, and vitamin E deficiency. Other types of neuropathy that can be treated according to the invention include inflammation-induced nerve damage, neurodegeneration, hereditary neuropathy, e.g., Friedreich ataxia, familial amyloid polyneuropathy, Tangier disease, and Fabry disease, metabolic disorders, e.g., renal insufficiency and hypothyroidism, infectious and viral neuropathies, e.g., neuropathic pain associated with leprosy, and Lyme disease. Auto-immune neuropathies include Guillain-Barre syndrome, chronic inflammatory de-myelinating polyneuropathy, monoclonal gammopathy of undetermined significance and polyneuropathy, trigeminal neuralgia and entrapment syndromes, e.g., Carpel tunnel syndrome, and other neuropathic pain syndromes including post-traumatic neuralgia, phantom limb pain, multiple sclerosis pain, complex regional pain syndromes, e.g., reflex sympathetic dystrophy, causalgia, neoplasia- associated pain, vasculitic/angiopathic neuropathy, and sciatica.

Tactile Allodynia

Tactile allodynia is a condition in which pain is evoked by stimulation of the skin (*e.g.* touch) that is normally innocuous. Tactile allodynia can be treated by administering to the subject a pharmaceutically effective amount of a dimer of the invention. The dimer can be administered alone or in conjunction with an effective amount of an analgesic agent.

A dimer of the invention can be co-administered with a therapeutic agent such as an anti-cancer agent or an anti-viral agent. Examples of anti-cancer agents include taxol, taxotere, cisplatin, nocodazole, vincristine, vindesine and vinblastine. Examples of anti-viral agents include ddI, DDC, d4T, foscarnet, dapsone, metronidazole, and isoniazid.

Reduction of Loss of Pain Sensitivity

Compositions of the invention can be used for reducing the loss of pain sensitivity, e.g., loss of thermal pain sensitivity, in a patient with diabetic neuropathy. Treatment can be prophylactic or therapeutic.

In prophylactic treatment, a dimer of the invention is administered to a patient at risk of developing loss of pain sensitivity, e.g., a patient with an early stage neuropathy.

In therapeutic treatment, a dimer of the invention is administered to a patient who has experienced loss of pain sensitivity as a result of a neuropathy, e.g., a late stage neuropathy.

Viral-Associated Neuropathies

Compositions and methods of the invention can be used for prophylactic treatment of neuropathies associated with viral or bacterial infection. Prophylactic treatment is indicated after determination of infection and before onset of neuropathic pain. During treatment, a dimer of the invention is administered to prevent appearance of neuropathic pain such as neuropathic pain associated with leprosy, Lyme disease, or neuropathic pain caused by a virus. Viruses that can cause neuropathic pain include herpes zoster virus (which may lead to post-herpetic neuralgia); human immunodeficiency virus (HIV); and human papilloma virus (HPV).

Symptoms of acute viral infection often include the appearance of a rash. Other symptoms include, for example, persistent pain in the affected area of the body. This is a common complication of a herpes zoster infection (shingles). Post-herpetic neuralgia can last for a month or more, and may appear several months after any rash-like symptoms have disappeared.

The invention also provides for therapeutic treatment of neuropathic pain associated with viral or bacterial infection. In therapeutic treatment, a dimer of the invention is administered to a patient who is experiencing neuropathic pain associated with infection.

Painful Diabetic Neuropathy

Compositions and methods of the invention can be used for prophylactic treatment of painful diabetic neuropathy. Prophylactic treatment of diabetic neuropathies would commence after the initial diagnosis of diabetes or diabetes-associated symptoms and before onset of neuropathic pain. Prophylactic treatment of painful diabetic neuropathy also may commence upon determining that a subject is at risk for developing diabetes or diabetes-associated symptoms. A dimer of the invention is administered to prevent appearance of neuropathic pain and/or to to reduce the severity of neuropathic pain that has already appeared.

The invention also provides for therapeutic treatment of neuropathic pain associated with diabetes. In therapeutic treatment, a dimer of the invention is administered to a patient who is experiencing neuropathic pain associated with diabetes.

Dosage and Route of Administration

Preferably, a formulation comprising a dimer of the invention is administered at a dosage from 0.1μg/kg to 1000 μg/kg body weight of the subject, per dose. Preferably the dosage is from 1 μg/kg to 100 μg/kg body weight of the subject, per dose. More preferably the dosage is from 1 μg/kg to 30 μg/kg body weight of the subject, per dose, e.g., from 3 μg/kg to 10 μg/kg body weight of the subject, per dose. Therapeutically effective amounts of the formulation of the invention may be administered to a subject in need thereof in a dosage regimen ascertainable by one of skill in the art, without undue experimentation.

Administration dimer of the invention can be systemic or local. It can be administered by any suitable delivery system, e.g., intravenous delivery, intramuscular delivery, intrapulmonary delivery, subcutaneous delivery, and intraperitoneal delivery, most preferably via intramuscular delivery, intravenous delivery, or subcutaneous delivery. The dimer also can be administered intrathecally.

The invention is further illustrated in the following non-limiting examples.

EXAMPLES

Example 1: Expression in Mammalian Cells

Mature human Neublastin (hNBN) is naturally expressed as a pre-pro-protein. This polypeptide contains a signal peptide sequence for direction of the protein into the secretory pathway, a prodomain that is cleaved and discarded upon maturation, and a mature protein. The mature protein of 113 amino acids contains a single glycosylation site and seven cysteine residues. The seven cysteine residues are involved in three intramolecular disulfide linkages plus a single intermolecular disulfide bond to form a disulfide linked, glycosylated homodimer.

<u>Construction of plasmid pJC070.14</u> In order to express the human neublastin cDNA in Chinese hamster ovary (CHO) cells, a cDNA fragment encoding the prepro form of human neublastin was inserted into the mammalian expression vector pEAG347 to generate plasmid pJC070.14. The plasmid pEAG347 contained tandem SV40 early and adenovirus major late promoters (derived from plasmid pAD2beta; Norton et al., 1985, *Mol. Cell. Biol.* 5:281), a unique Not-I cloning site, followed by SV40 late transcription termination and polyA signals (derived from plasmid pCMVbeta; MacGregor et al., 1989, *Nucl. Acids. Res.* <u>17</u>:2365). In addition, pEAG347 contained a pUC19-derived plasmid backbone and a pSV2dhfr-derived dhfr for MTX selection and amplification in transfected CHO cells.

Plasmid pJC070.14 was generated in two steps. First, a fragment encoding the prepro form of human neublastin was isolated from plasmid pUbi1Z-NBN using the polymerase chain reaction with oligonucleotides KD2-824 5'AAGGAAAAAA GCGGCCGCCA TGGAACTTGG ACTTGGAGG3' (SEQ ID NO:22), KD2-825 5'TTTTTTCCTT GGCGGCCGCT CAGCCCAGGC AGCCGCAGG3' (SEQ ID NO:23) and PFU polymerase. The fragment was cloned into the Srf-1 site of pPCR-Script Amp SK(+) to generate the plasmid pJC069. In the second step, a partial Not-1 digest was performed on plasmid pJC069 to generate a 685bp fragment (containing the neublastin gene) which was cloned into the Not-1 site of plasmid pEAG347 to generate plasmid pJC070.14. Transcription of the neublastin gene in plasmid pJC070.14 was controlled by the adenovirus major late promoter.

CHO cell lines expressing human Neublastin. First, 200 μg of pJC070.14 was linearized by digestion with Mlu-1. Then 200ug of sonicated salmon sperm DNA was added. The DNA was extracted with phenol:chloroform:isoamyl alcohol (25:24:1) and ethanol-precipitated. The linearized DNA was resuspended in 20mM Hepes pH7.05, 137mM NaCl, 5mM KCl, 0.7mM Na_2HPO_4, 6mM dextrose (HEBS) and introduced into ~4E7 CHO dukx B1(*dhfr-*) cells (p23) by electroporation (280V and 960 μF). Following electroporation, the cells were returned to culture in α+ Modified Eagle's Medium (MEM) supplemented with 10% fetal bovine serum (FBS) for two days. The cells were then trypsinized and replated in 100 mm dishes (100,000 cells/plate) in α-MEM (lacking ribo- and deoxyribonucleosides), supplemented with 10% dialyzed FBS, for five days. The cells were subsequently split at a density of 100,000 cells/100mm plate, and selected in 200nM methotrexate. Resistant colonies were picked and scaled up to 6 well plates; conditioned media from each clone was screened using a specific assay for neublastin described below.

Twelve clones expressing the highest level of neublastin were scaled up to T162 flasks and subsequently re-assayed. These CHO cell lines produced neublastin in the range of 25-50 ng/ml/day. The four best neublastin-expressing cell lines were amplified in 1200nM methotrexate and adapted to suspension culture in spinner flasks. The resulting clones produced approximately 2ug/ml in high density spinner culture.

Ternary complex assay for Neublastin. The presence of neublastin was assessed in the media of CHO cell line supernatants using a modified form of a ternary complex assay. The assay was essentially as described by Sanicola et al., 1997, *Proc. Natl Acad Sci USA* 94:6238.

Expression of NBN104 in CHO Cells. A 104-amino acid form of mature hNBN was expressed in Chinese Hamster Ovary (CHO) cells by the following procedure. A synthetic hNBN gene was created using codons most commonly utilized for translation of proteins in CHO cells. A unique restriction endonuclease cleavage site was introduced. The codons for the rat albumin (rAlb) signal peptide, i.e., MKWVTFLLLLFISGSAFS*AAGARG* (SEQ ID NO:24), and the sequence for the human growth hormone (hGH), i.e.,

MATGSRTSLLLAFGLLCLSWLQEGSA*AAGARG* (SEQ ID NO:25), were fused independently to hNBN to create fusion genes (the signal peptide is in regular font and the NBN sequence is in italics; the hGH signal peptide includes an intron). Each fusion gene was placed under transcriptional control of a constitutive promoter and transfected into CHO cells. Stable transformants were isolated.

The cell lines were analyzed for expression of secreted hNBN. Data from reducing SDS-PAGE / Western blot analysis demonstrated the presence of a protein band corresponding to hNBN secreted into the medium. Further analysis of the conditioned medium demonstrated the presence of a titratable component in both a direct, antibody-driven assay as well as an indirect, cell-based, functional assay.

The conclusion is that functional hNBN can be expressed in CHO cells in the absence of a prodomain and with heterologous signal peptide sequences.

Example 2: Expression of Rat Neublastin in CHO Cells

Construction of plasmid pCWEX017.1. A gene for rat neublastin was generated by ligating two fragments that together encode rat neublastin. Plasmid pJC102 consisted of a DNA fragment encoding the first 156 amino acids of rat prepro form of neublastin inserted into the TOPO cloning site of pCRII –TOPO r (Invitrogen). The fragment was amplified from Marathon-Ready t rat liver cDNA (Clontech) using the polymerase chain reaction with oligonucleotides AP2 5'ACTCACTATAGGGCTC GAGCGGC3' (SEQ ID NO:26) and KD3-171 5'GAACCGCTGCAGAAGCGGAAACGTATC3'(SEQ ID NO:27). A fragment containing the prepro domain and first 29 amino acids of the mature 113 amino acid form of neublastin was first amplified using the polymerase chain reaction from the plasmid pJC102 with the oligonucleotides KD3-214 5'AAGGAAAAAAGCGGCCGCCATGGAACTGGGACTTGGAGA3'(SEQ ID NO:28) and KD3-247 5'AGTTCGTCGGAAGAGTGTCCCAGGCCGAGAGCGC TCACCG3'(SEQ ID NO:29). A second fragment encoding amino acids 30-113 of the mature 113 amino acid form of neublastin was amplified from pCWEX015 with the oligonucleotides KD3-246 5'CGGTGAGCGCTCTCGGCCTGGGACACTCTT

CCGACGAACT3'(SEQ ID NO:30) and KD3-219 5'TTTTTTCCTTGGCGGCCGCT CATCCTAGACAGCCACATG3'(SEQ ID NO:31). The plasmid pCWEX015 was generated by inserting a BamH1-Xho1 fragment from a syngene into the complementary sites of the expression plasmid pMJB134. The resultant DNA fragments were mixed at a 1:1 ratio and submitted to a second polymerase chain reaction with oligonucleotides KD3-214 and KD3-219 generating the full length prepro form of rat neublastin. The resultant DNA fragment was cloned into the TOPO cloning site of the plasmid pCRII blunt-topo to generate pCWEX016. A Not-1 fragment containing the entire prepro neublastin was isolated and cloned into the Not-1 Site of pEAG347 to make pCWEX017.1.

Sequence of Rat Neublastin Synthetic Gene

GCTCGAGCGGCCATATCGACGACGACGACAAGGCTGGAACTCGCAGCTCT
CGTGCTCGTGCAACCGATGCACGTGGCTGTCGTCTGCGTTCTCAACTAGTG
CCGGTGTCTGCACTCGGACTGGGACACTCTTCCGACGAACTAATTCGTTTT
CGTTTTTGTTCAGGATCTTGTCGTCGTGCACGTTCTCCGCATGATCTATCTC
TAGCATCTCTACTAGGAGCCGGAGCACTAAGATCTCCGCCGGGATCTAGA
CCTATTTCTCAACCTTGTTGTAGACCTACTAGATACGAAGCAGTATCTTTC
ATGGACGTAAACTCTACATGGAGAACCGTAGATCATCTATCTGCAACCGC
ATGTGGCTGTCTAGGATGATAATAGGGATCCG (SEQ ID NO:32)

CHO cell lines expressing rat Neublastin. 200 μg of plasmid CWEX017.1 was linearized by digestion with the restriction endonuclease Mlu-1. After digestion, 200ug of sonicated salmon sperm DNA was added and the mixture was extracted with phenol: chloroform:isoamyl alcohol (25:24:1) and ethanol precipitated. The linearized DNA was resuspended in 20mM Hepes pH7.05, 137mM NaCl, 5mM KCl, 0.7mM Na_2HPO_4, 6mM dextrose (HEBS) and introduced into ~4E7 CHO DG44 (*dhfr-*) cells (p8) by electroporation (280V and 960 μF). Following electroporation, the cells were returned to culture in α+ Modified Eagle's Medium (MEM)

supplemented with 10% fetal bovine serum (FBS) for two days. The cells were then trypsinized and replated in 100 mm dishes (100,000 cells/plate) in α-MEM (lacking ribo- and deoxyribonucleosides), supplemented with 10% dialyzed FBS. After six days in culture, the media was replaced and the cells were selected in 200nM methotrexate. Resistant colonies were picked and scaled up to 6 well plates; conditioned media from each clone was screened using the ternary complex assay for neublastin referenced above. The five clones expressing the highest level of neublastin were scaled up to T162 flasks and subsequently re-assayed. These CHO cell lines produced Neublastin in the range of 500 ng/ml/day. The highest expressing lines were subsequently adapted to suspension culture and express neublastin at approximately 2ug/ml in high density spinner culture.

<u>PEGylated CHO-derived rat neublastin.</u> One hundred liters of CHO cells expressing rat NBN (clone 33s) were grown for 10 days at 37C in BCM16 medium containing 200 nM methotrexate. The culture was filtered and concentrated 10-fold. Hepes pH 7.5 was added to a final concentration of 10 mM and the medium was loaded overnight at 4C onto a 120 mL SP-Sepharose column (Pharmacia). The column was washed with 10 mM Hepes pH 7.5, 100 mM NaCl and bound protein eluted from the column with a gradient of NaCl (0.1- 1M) in 10 mM Hepes pH 7.5. Samples were analyzed for absorbance at 280 nm, for total protein by SDS-PAGE, and for functional NBN using the RetL3 ternary complex ELISA. NBN activity was found at the trailing edge of the protein peak. Peak NBN-containing fractions from the SP column were pooled, diluted 5-fold with 10 mM Hepes 7.5, loaded onto a 22 mL Heparin Sepharose column (Pharmacia). The column was washed with 110 mL of 10 mM Hepes pH 7.5, 500 mM and NBN was eluted with 10 mM Hepes pH 7.5, 1M NaCl. NBN-containing fractions were identified by SDS-PAGE and pooled. The pooled fraction was diluted with 10 mM Hepes pH 7.5 to a final salt concentration of 150 mM. The protein was loaded onto a 20 mL SP-Sepharose column and again eluted with a gradient of NaCl. NBN-containing fractions were identified by SDS-PAGE, pooled, filtered and stored at –70C. Protein context was estimated from absorbance at 280 nm using an extinction coefficient of 0.5 for a 1 mg/mL solution. The purified CHO NBN migrated as a single broad band by SDS-PAGE under non-

reducing conditions with an apparent mass of 36 kDa and under reducing conditions migrated as a band with an apparent mass of 18 kDa. N-terminal sequence analysis revealed that the N-terminus of the product was heterogenous due to cleavage at alternative sites producing des 1-4, des 1-7, and des 1-9 adducts.

To remove N-terminal heterogeneity in the purified NBN the protein was treated for 2 h at 37C at pH 8.5 with a 1:100 (w/w) ratio of trypsin to NBN and purified on a Superdex 75 gel filtration column in 10 mM Hepes pH 7.5, 300 mM NaCl. Peak NBN-containing fractions were identified by SDS-PAGE, pooled (0.9 mg/mL final), filtered through a 0.2 μm filter, aliquoted and stored at –70C for subsequent studies. N-terminal sequencing of the NBN after trypsin-treatment revealed that the protein had been converted to a des 1-9, 104 amino acid form, starting with the sequence ATDARGC. Mass spectroscopy data for the reduced and deglycosylated product revealed a mass of 11104 Da, which agreed exactly with the predicted mass for the des 1-9 form of NBN.

The purified des 1-9 NBN was thawed at room temperature. Hepes pH 7.5 was added to 50 mM from a 1 M stock and 20K NHS-SPA PEG (Shearwarter Polymers, Inc.) was added to a final concentration of 8 mg PEG/mL. The final NBN concentration in the reaction was 0.7 mg/mL. The sample was incubated at room temperature for 3 h and then dialyzed overnight at 4C against 50 volumes of 10 mM Hepes pH 7.5, 100 mM NaCl. The dipegylated form was purified from other reaction products and free PEG by SP-Sepharose cation exchange chromatography at room temperature at a load concentration of 3mg NBN/mL of resin. The column was washed with 4-one half column volume fractions of 10 mM Hepes pH 7.5, 150 mM NaCl, then the dipegylated product was eluted with 4-one half column volume fractions of 10 mM Hepes pH 7.5, 200 mM NaCl. Monopegylated NBN was then eluted with of 10 mM Hepes pH 7.5, 350 mM NaCl and unreacted NBN with of 10 mM Hepes pH 7.5, 800 mM NaCl. NBN-containing fractions were evaluated by SDS-PAGE and fractions containing >90% of the dipegylated product were pooled, dialyzed overnight against PBS and filtered through a 0.2 μm filter. Endotoxin levels were measured and were determined to be less than 1 EU/mg. The material was tested for function in the KIRA ELISA and neuronal survival assay and determined to

be fully active. The final material was aliquoted and stored at –70C for subsequent testing. In early studies the monopegylated product was also collected for in vivo testing. However because of the better properties of the dipegylated material it was selected for all subsequent. To increase the yield of dipegylated material we further treated the monopegylated NBN with fresh PEG and again purified the dipegylated product from the reaction mix.

Example 3: Pharmacokinetics of PEGylated and Glycosylated Neublastin

The pharmacokinetic properties of PEGylated, gylcosylated neublastin in rat and mouse were examined. N-terminal PEGylation of glycosylated, truncated rat neublastin (N-terminus truncation of 9 amino acids; NBN104) with two 20,000 Da PEG moieties (2 X 20KDa PEG NBN104) yielded a significant improvement in half-life and bioavailability of the neublastin. Following a 1.5 mg/kg subcutaneous administration to CD mice, serum levels of 97 ng/ml of PEGylated, glycosylated neublastin were detected at 24 hours. In contrast, following a 1.5 mg/kg subcutaneous administration of non-glycosylated NBN pegylated with two 20000 Da PEGs (2 X 20KDa PEG) to mice, neublastin serum levels were 39 ng/ml at 24 hours. Neublastin was not detectable at 24 hours following a 1.5 mg/kg subcutaneous administration of unmodified glycosylated NBN104 to mice, indicating that serum levels of neublastin were less than 5 ng/ml. Surprisingly, the serum level achieved with the PEGylated, glycosylated neublastin was approximately 2.5-fold greater than the serum levels achieved with PEGylated, non-glycosylated neublastin.

Increased serum levels of N-terminus PEGylated, glycosylated neublastin were also observed in rat studies. Following a 1 mg/kg s.c. administration of 2 X 20KDa PEG NBN104 to Sprague-Dawley rats, peak serum levels of 50 ng/ml of PEGylated neublastin were detected at 48 hours. Following a 1 mg/kg subcutanteous administration of non-PEGylated neublastin, serum levels at 48 hours were less than 2 ng/ml. These data indicated that N-terminal PEGylation of glycosylated neublastin (2 X 20KDa PEG NBN104) resulted in peak serum levels of neublastin that were at least 19-fold greater than peak serum levels attained after administration of non-PEGylated, glycosylated neublastin. These data demonstrated that the combination of

PEGylation at the N-terminus and glycosylation at amino acid 95 yielded a substantial enhancement of pharmacokinetic properties and bioavailability of neublastin.

Example 4: PEGgylated, Glycosylated Neublastin in Animal Model of Neuropathic Pain

The reversal effect of PEGylated, glycosylated neublastin on tactile allodynia and thermal hyperalgesia was studied in the Chung L5/L6 spinal nerve ligation ("SNL") model. Sprague-Dawley male rats (200 - 250g) were divided into three groups. All rats received the spinal nerve ligation. One group of rats (n=6) was administered vehicle by subcutaneous injection. A second and third group of rats (n=6 per group) were administered 3 and 30 μg/kg PEGylated, glycosylated neublastin (2 X 20KDa PEG NBN104) by subcutaneous injection, where the protein was CHO-derived, truncated (N-terminus truncation of 9 amino acids; NBN104), and PEGylated on each N-terminus with a 20,000 Da PEG. Since neublastin exists as a dimer, each dimer contains two 20,000 Da PEGs. The vehicle consisted of 5mM phosphate and 150mM sodium chloride at pH 6.5. Subcutaneous injections were administered on days 3, 5, 7, 10, 12 and 14 following the operation (post-SNL). The Von Frey and Hargreave's behavioral tests (Chaplan et al., 1994, *J. Neurosci. Meth.* 53:55-63; Hargreaves et al., 1988, *Pain* 32:77-88) were used to monitor tactile and thermal responses, respectively. These pain responses were monitored prior to the spinal nerve ligation to establish baseline responses, and then prior to drug administration on day 3 post-SNL, and approximately 1 hour following drug administration on days 5, 7, 10, 12 and 14 post-SNL. To assess statistical significance of drug treatment relative to vehicle treatment, a 2-way repeated measure analysis of variance (2-way RM ANOVA) was carried out followed by a post-hoc Student Neuman Keuls (SNK) test.

The results are summarized in FIGS. 1 and 2 (as averages ± standard errors of the mean). Both types of neuropathic pain behavior (tactile allodynia shown in FIG. 1, and thermal hyperalgesia shown in FIG. 2) developed fully by day 3, as expected. Subcutaneous administration of 3 or 30 μg/kg 2 X 20KDa PEG NBN104 (denoted by downward arrows in FIGS. 1 and 2) led to substantial and statistically significant

reversal of both types of neuropathic pain in rats with spinal nerve ligation. In rats with spinal nerve ligation, the effect of 2 X 20KDa PEG NBN104 on thermal sensitivity and tactile allodynia first became statistically significant 4 and 7 days, respectively, after the initiation of administration of pegylated glycosylated neublastin. The effect of 2 X 20KDa PEG NBN104 on thermal sensitivity and tactile allodynia reached a plateau approximately 7 days after the initiation of administration of pegylated glycosylated neublastin. The effects of 2 X 20KDa PEG NBN104 did not diminish during the 2 to 3 day interval between administrations. In fact, there was substantial normalization of pain behaviors between the administrations of pegylated glycosylated neublastin on days 5, 7 and 10.

These results demonstrated that 2 X 20KDa PEG NBN104 has at least a 333-fold increased potency over non-PEGylated, non-glycosylated neublastin on tactile allodynia and thermal hyperalgesia pain behaviors in the SNL model.

OTHER EMBODIMENTS

Other embodiments are within the following claims.